PRODUCTION OF THE HIGH QUALITY TORREFIED OIL PALM BIOMASS FOR EFFICIENT ENERGY APPLICATION

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ABSTRACT

The modern technology nowadays has led to a high consumption of energy where renewable energy sources become one of the hottest topics among the scientists. Biomass, as one of the promising renewable energy sources become the most attractive energy source in the world. Hence, this study aims to produce the high quality of torrefied oil palm biomass for efficient energy application. Torrefaction is known as the mild form of pyrolysis where the process occurs at atmospheric pressure and the temperature ranging of 473-573 K with the absence of oxygen. The raw materials selected for the study are the empty fruit bunch (EFB), mesocarp fiber and the kernel shell. The main reason of selected oil palm waste as the biomass raw material is due to its availability as Malaysia is the second largest producer of palm oil in the world. The experiment was carried out by using a tubular reactor which was located at the Gas Engineering Lab of University Malaysia Pahang. Results obtained showed that the powder form of all the samples have fully decomposed after torrefaction process, hence, the experiment was carried on with the fibrous form of samples for a better scale of study. The calorific value (CV) determined using a bomb calorimeter and the result collected showed a trend of increased in CV for all the samples started from EFB to kernel shell as the temperature increased. While for the case of mass yield, the trend was decreased for all the samples when the temperature increased along the torrefaction process. This was due to the thermal decomposition of the structure of samples during the experiment. This had directly affected the trend of energy yield by all the samples as the optimization of energy yield was not achieved at 100% except for kernel shell at 523K and 573K. Fourier Transform Infrared Spectroscopy (FTIR) test was also carried out in order to determine the component and chemical compositions which existed before and after the experiment, and results showed that the structure of the samples was mainly remain the same after the process.

Key words: torrefaction, oil palm biomass, calorific value, mass yield, energy yield, FTIR

ABSTRAK

Zaman moden teknologi kini telah menyumbang kepada penggunaan tenaga yang melambung naik sehingga kajian terhadap sumber tenaga baru menjadi topik terhangat di kalangan scientist di dunia. Biomas, dikenali sebagai sumber tenaga boleh diperharui yang terpenting di dunia untuk dijadikan sebagai bahan api. Namun begitu, biomas masih mempunyai sesetengah kelemahan dari segi sifat-sifat kimia dan fizikal yang perlu ditangani untuk menjamin prestasi biomas sebagai sumber tenaga. Tujuan kajian ini ialah memajukan prestasi biomas sebagai sumber tenaga melalui proses torrefasi. Torrefasi dijalankan untuk menjamin kualiti biomas tanaman bijih timah dalam pembekalan sebagai sumber tenaga. Torrefasi merupakan satu proses yan berlaku pada tekanan atmosfera dalam suhu di lingkungan 473-573 K tanpa melibatkan kewujudan oksigen. Biomas tanaman bijih timah yang terpilih adalah EFB, mesocarp fiber dan kernel shell. Biomas tanaman bijih timah dipilih sebagai bahan mentah untuk kajian ini adalah disebabkan Malaysia merupakan pembekal bijih timah yang kedua terbesar di dunia dan ini dapat menjamin pembekalan biomass bijih timah yang berlanjutan. Eksperimen torrefasi dijalani dengan menggunakan reaktor tiub yang terdapat di makmal kejuruteraan gas yang bertempat di Universiti Malaysia Pahang. Merujuk kepada keputusan yang diperolehi, serbuk bahan mentah didapati mengurai sepenuhnya selepas proses torrefasi dan ini mengakibatkan tiada hasil keputusan untuk dianalisasi. Nilai kalori pula ditentukan dengan menggunakan bom kalorimeter dan keputusan menunjukkan nilai kalori kian meningkat untuk semua sample bahan mentah. Untuk kajian nilai hasil berat sample bahan mentah, trend menujukkan kejatuhan nilai hasil berat yang disebabkan oleh penguraian sample bahan mentah selepas proses torrefasi. Nilai hasil tenaga tidak mencapai keputusan yang sepatutnya kerana kerendahan nilai hasil berat bahan mentah menjejaskan nilai hasil tenaga yang sepatutnya. Manakala untuk kajian FTIR, keputusan menunjukkan struktur bahan mentah tidak mempunyai perbezaan yang ketara sebelum dan selepas proses torrefasi.

Kata Kunci: torrefasi, biomass tanaman bijih timah, nilai kalori, nilai hasil berat, nilai hasil tenaga, FTIR

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CV	Calorific Value
FTIR	Fourier Transform Infrared
HHV	High Heat Value
MC	Moisture Content
MSW	Munipal Solid Waste
Ym	Mass Yield
Ye	Energy Yield

CHAPTER 1

INTRODUCTION

1.1 Background

Fossil fuels are the primary energy source in the past and today's transportation fuel supply. However, the fossil fuels are not renewable and the applications of fossil fuels bring environmental problems which endangered the health of human being (Ren et al., 2012). Due to the worldwide environmental issues such as greenhouse effect, acid rain and global warming situation, the utilization of renewable energy source has consequently become increasingly of interest (Wannapeera & Worasuwannarak, 2012). The transition to a society driven by renewable energy sources such as solar, wind, biomass, tide, wave and geothermal energy next to energy savings becomes even more an important alternative in the field of energy consumption. According to the World Energy Outlook, renewable energy sources are expected to be the fastest growing energy sources. Biomass is known as the only renewable source that is based on sustainable carbon among this spectrum of several different energy sources (Stelt et al., 2011). Biomass acts as an important role in the future energy scenarios. This is due to its unique position as the only renewable source as sustainable carbon carrier caused it to be an attractive energy source. Unlike fossil fuels, biomass is planted and collected annually that can provide a continuous energy supply and hence is known as one of the most important and large renewable fuel sources (Ren et al., 2012). Biomass can be converted into energy via thermo chemical conversions, biochemical conversions and extraction of oil from oil bearing seeds (Stelt et al., 2011). However, biomass is classified as the low grade fuel due to its undesired properties such as high moisture content, high ash content and low energy density. Therefore, direct utilization of biomass seems to face great obstacles in overcoming the above drawbacks. (Wannapeera & Worasuwannarak, 2012).

In order to overcome the undesired properties of biomass, many experiment methods have been carried out such as pelletisation, gasification, pyrolysis or torrefaction process, hence this lead to this study on torrefaction process. As mentioned in the study of Bergman (2005), densification by means of pelletisation is considered to be the proven technology to improve biomass properties for its conversion into heat and power. The biopellets market is becoming quite mature with serious outlets in the domestic market and the energy market after a significant increase of pellets production in Europe and Northern America. It is believe that biopellets are a major sustainable fuel to replace coal. While for the gasification, it is the partial oxidation of carbonaceous feedstock above 800 °C to produce a syn-gas that can be used for many applications such as gas turbines, engines, fuel cells, producing methanol and hydrocarbon. It is desirable that gasification becomes increasingly applied in future rather than direct combustion due to its higher efficiency. It is believed that coupling gasification with power systems increases the efficient use of thermal energy streams (Stelt et al., 2001). Pyrolysis is a thermal chemical technology conducted at the range of temperature of 400-600°C in the absence of oxygen. However, pyrolysis biomass is normally heated and decomposed to produce liquid biomass such as hydrocarbon biofuel (Ren et al., 2012). In order to obtain solid wastes as products, torrefaction process is the preferable method. According to Bergman (2005), torrefaction is a thermal chemical treatment of biomass at 200-300˚C which is carried out under atmospheric conditions and the absence of oxygen. The techniques is carried out under a relatively low range of temperature (200-300˚C) which aims to enhance the fuel properties attractively for further utilization such as combustion, gasification and co-combustion (Bergman, 2005).

1.2 Motivation

Malaysia as a tropical country experiences hot and wet weather throughout the year. Besides that, Malaysia is with abunbant and relatively cheap supply of conventional fossil energy resources such as oil, gas, and coal as well as renewable energy sources such as hydropower, biomass and solar. According to Yusoff (2004), past and current economic growth in the country has been primarily fueled by fossil fuels. However, recently, the economic recovery upward trend combined with recent strategies to minimize the cost as much as possible has developed a supportive environment to incorporate energy conservation and energy efficiency measure as part of the nation's "Vision 2020" industrialization objectives. This also in line with the primary national energy policy objectives of the country, under its utilization objective, namely, to promote and encourage the efficient utilization of energy as well as discourage wasteful and unproductive patterns of energy consumption. Hence, this is lead to the study of this process. Besides that, over the last few decades, the Malaysian palm oil industry has grown to become a very important agriculture-based industry, where the country is today one of the world's leading producer and exporter of palm oil. Malaysia as the second largest producer of palm oil which come after Indonesia, covered 41% of the total world supply ensure a continuous supply of oil palm waste which been chosen as the raw materials of biomass for this study. Due to its availability in Malaysia, oil palm waste are considered as the best among all biomass waste and this directly lead to the reason why oil palm waste as torrefied biomass is the topic of this study. As can been seen previously, most of the torrefaction biomass process are emphasized on the woody mass such as the TOP process by Bergman (2005) and the upgrading of woody biomass by torrefaction of Wannapeera & Worasuwannarak (2012). Besides that, according to Masuda et al., 2001, the amount of oil palm solid wastes sums up to 26 million tonnes per year, which is about three times as large as the total amount of plastics discarded in Japan annually. Hence, it is necessary to carry out more study on the other raw materials of biomass instead of woody biomass especially oil palm wastes. A full utilization of oil palm waste as biomass will ensure an economical advantage towards the development of Malaysia in the field of renewable source, meanwhile, reduce the rate of environmental issues especially the carbon emission to the environment. Moreover, oil palm is a perennial tree crop, which is cultivated extensively in the humid tropical land. Average planting cycle of a palm tree is about 25 years for efficient productivity. This is due to the conversion of solar radiation to plant growth by photosynthesis, the chemical energy content of the harvested palm fruit and biomass exceeds the energy input through the farming system. These palm residues contain high nutrient value. Based on the nutrient content estimation by Yusoff (2004), an equivalent energy of 683.2 MJ is saved from the production of chemical fertilizer if the palm residues are used as fertilizer.

1.3 Problem Statement

Biomass is known as the only renewable source that is based on sustainable carbon among this spectrum of several different energy sources (Stelt et al., 2011). However, it still be treated as a low grade fossil fuel due to its undesirable properties. Hence, many researches have been carried out in improving the properties of biomass which can enhance its performance as fossil fuel. Torrefaction process has been selected as the main process of study in this research. Torrefaction is widely known as a thermal chemical treatment process of biomass which is carried out under the atmospheric pressure with the temperature range of 200-300 ˚C with the absence of oxygen (Bergman, 2005). It is also known as a mild form of pyrolysis, and is preferred compare to slow and fast pyrolysis due to the reason of the biomass used in this study is oil palm solid waste materials. Pyrolysis biomass is normally heated and decomposed to produce liquid biomass such as hydrocarbon biofuel (Ren et al., 2012). On top of that, the selected biomass material for this study is the oil palm solid waste materials which are the empty fruit bunch (EFB), mesocarp fiber, and kernel shell. All of this solid biomass will undergo the torrefaction process and consequently, torrefied biomass is obtained. Research showed that the torrefaction process successfully overcome the undesired properties of biomass. It was stated that torrefaction process was found to be effective for improving the energy density and shelf life of the biomass (Uemura et al., 2011).

1.4 Objectives

This study aims to produce the high quality of torrefied oil palm biomass for efficient energy application.

1.5 Scope

The study emphasize on the torrefaction of oil palm wastes as biomass where two main parameters will be tested in the study as shown below.

- Effect of different temperature ranging within 200-300°C.
- Effect of total surface area of biomass particles (Fibrous and Powder form).

The two parameters mentioned will be used to test on the moisture content and calorific value (CV) which contribute to the calculation of mass yield and energy yield. Hence, the characteristics of oil palm waste before and after torrefaction will be discuss in order to achieve the purpose of choosing torrefied oil palm biomass for energy application. The range of temperature set will be around 200-300˚C, where graphs will be plotted accordingly to the result obtained. In this study, the oil palm solid wastes included are the empty fruit bunches (EFB), mesocarp fibre, and palm kernel shell. Once the experiment carried on, the properties of each raw material were characterized for their calorific value, moisture content, mass yield and energy yield. The experiment will be conducted in a pyrolyzer which is a horizontal tubular type reactor by differing the temperature in the ranging of 200-300°C located at the gas engineering lab in the FKKSA Laboratory of University Malaysia Pahang. While for the characterization of moisture content will be carry out by using an electric oven which located in the environmental engineering lab at the temperature of 105°C for duration of one hour. The calorific value is tested by using the bomb calorimeter which located at the basic engineering lab of UMP. CV ratio will be calculated based on the calorific value obtained in order to determine the energy yield of the study. Lastly, FTIR analysis will be carried out to determine the bonds exist before and after the torrefaction process which occurred at different values of temperature. The analysis was carried out by using the spectrometer located at Faculty of Industrial Science and Technology of University Malaysia Pahang.

1.6 Structure of Thesis

Chapter 2 mainly discussed on the information gather and the review done by this study towards the topic concerned. It started with the review of biomass and types of biomass in the world, and is followed by the review of palm oil industry in Malaysia together with the palm oil solid wastes used in this study. Last part of this chapter was done on the biomass conversion techniques and methods used in industry. Meanwhile, comparison between the recent literature and pass researches also have been done in order to get a better review.

Chapter 3 was discussed on the samples and methods used along the experiment. Hence, methods used to characterize moisture content, calorifiv value, FTIR analysis and reactor used to run the torrefaction process were discussed and presented. Besides that, measurements used for the calculations of mass and energy yield was also discussed in this chapter.

Chapter 4 presented on the preliminary results and the final results obtained before and after the experiment. Hence, the effects of temperature on the mass and energy yields was dicussed within the chapter. The results obtained was used to compare with the pass researches in this chapter. Lastly, discussion on FTIR analysis was done based on the condition before and after torrefaction process.

CHAPTER 2

LITERATURE REVIEW

2.1 Chapter Overview

Palm oil industries in Malaysia generate about 90 million tonnes of renewable biomass (trunks, fronds, shells, palm press fiber and empty fruit bunches) per year, including about 1.3 million tonnes of oil palm trunks, 8 million tonnes of pruned and felled fronds, and 2.4 million tonnes of oil palm empty fruit bunches (EFB) (Alam et al., 2009). Hence, it is necessary to carry out more researches in order to make full use of all the oil palm solid waste produced throughout the year.

In this chapter, the research done related to the topic will be studied and reviewed especially the researches on different type of process which have been carried out to enhance the properties of oil palm solid waste. Meanwhile, the study on the properties of all the oil palm solid waste included will be reviewed as well.

2.2 Biomass and Types of Biomass

Biomass is any organic matter such as wood, crops, seaweed, animal wastes that can be used as an energy source, hence biomass can be understood as regenerative (renewable) organic material that can be used to produce energy (Oyemakinwa, 2011). For thousands of years, people have burned wood to heat their home and cook their food. These are the most basic examples of using biomass as an energy supply. As stated in the NEED project of Secondary Energy Infobook 2012, biomass is probably the oldest source of energy after the sun. Biomass gets its energy from the sun as all the organic matter contains stored energy from the sun through a process called photosynthesis. Along the process, sunlight gives the plants the energy that they need to convert water and carbon dioxide into oxygen and sugars. These sugars are called carbohydrates which supply the plants and animals that eat plants with energy. Consequently, biomass is known as a renewable energy source because it supplies are not limited due the reason of trees and crops can always grow and waste will always exist (Baumann et al., 2012). Figure 2.1 below showed the process of photosynthesis by the plant.

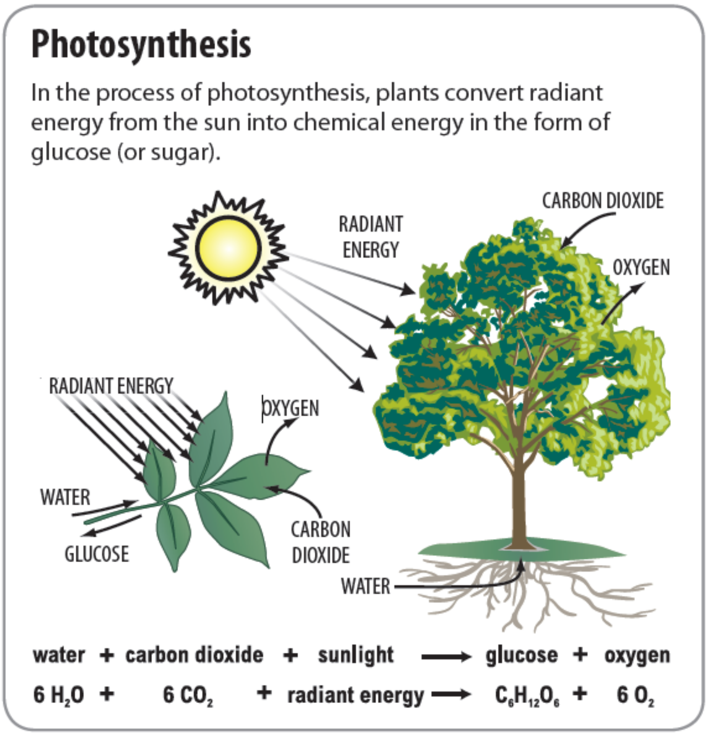

Figure 0-1: Process of Photosynthesis in Plant (Baumann et al., 2012)

Producing fuel and energy from biomass is a complex procedure but the principle behind it corresponds directly to the process of photosynthesis. In layman's term, that means biomass is manufactured from the wood and agricultural products, food waste, landfill gas and biogas, and lastly alcohol fuel (Oyemakinwa, 2011). The types of the following types of biomass will be further discussed in the subchapters below.

2.2.1 Woody Biomass

Woody biomass is best described as the material obtained from trees or the products of tress that has accumulated to a sufficient quantity that is a hazard of disposal problem or from trees specifically managed for biomass markets (Shelly, 2011). The previous definition also precludes wood and wood residue that would otherwise fit the definition except that they are already used to produce higher-value products, such as sawmill residues for particle board and other composite panels. Woody biomass is the solid portion of stems and branches from trees or residues products made from trees. Woody biomass can come from variety sources, including:

- Non-timber tree removal - removing dead and dying trees, unwanted urban trees or trees impeding land development.

- Forest management harvesting – the removal of small diameter trees from overpopulated stands for wildfire hazard fuel reduction, pre-commercial thinning of timber stands or forest health improvement.
- Timber harvesting and logging residues – non-merchantable wood including branches, undersized trees and non-commercial species removed during typical timber harvesting operations.
- Sawmill and other wood manufacturing residues – includes bark, undersized and defective wood pieces, sawdust and other wood waste.
- Landfill diversion – wood debris from tree removal and pruning, construction, demolition, discarded shipping materials and other trashed wood products.
- Chaparral management – removal of excess woody shrubs and plants for wildfire fuel hazard reduction or other vegetation management goals.

Woody biomass utilization is sometimes narrowly defined to mean the use of wood as a soure or feedstock solely for the production of energy (heat and electricity). This is short-sighted and often hinders the discovery of its full potential. It is important to remember that al though woody biomass is low in value and quality it has potential as a feedstock for energy pr oduction as well as for higher value manufactured goods (Shelly, 2011).

2.2.2 Municipal Solid Waste (MSW) as Biomass

Municipal solid waste (MSW) is defined as household waste, commercial solid waste, non-hazardous sludge, conditionally exempt, small quantity hazardous waste, and industrial solid waste. MSW includes food waste, rubbish from residential areas, commercial and industrial wastes, and construction and demolition debris. Biosolids which is the byproducts from waste water treatment, also know as sewage sludge are not included in the formal definition of municipal solid waste, though it is estimated that 20% of dry short tons of biosolids generated annually are handled by MSW landfills (Valkenburg et al., 2008).

The composition of MSW is mainly made up by the following materials,

- Paper or paperboard
- Food Scraps
- Wood
- Yard trimmings
- Plastics

- Metals
- Rubber, leather and textiles
- Glass

The origin of a given material can be very diverse and this complicates the picture. Some items, such as fridges or computers, are intricate machinery made of numerous components and many different materials (plastic, glass, metal, etc). Consequently, other categorising systems could be chosen such as listing of durable/non-durable goods or combustible/non-combustible matter. The classification system can and should be designed according to the need of its user. It is obvious that MSW is a complex and heterogenous mixture, made of materials with very different chemical structure and physical properties. However, a further obstacle is appearing: the category "other". This category is far from minute and may represent a significant share of the total MSW amount and can therefore make difficulties for waste management handling (Becidan, 2007).

2.2.3 Landfill Gas and Biogas as Biomass

Bacteria and fungi are not picky eaters. They eat dead plants and animals, causing them to rot or decay. A fungus on a rotting log is converting cellulose to sugars to feed itself. Although this process is slowed in a landfill, a substance called methane gas is still produced as the waste decays. New regulations require landfills to collect methane gas for safety and environmental reasons (Baumann et al., 2012).

Methane gas is colorless and odorless, but it is not harmless. The gas can cause fires or explosions if it seeps into nearby homes and is ignited. Landfills can collect the methane gas, purify it, and use it as fuel. Methane, the main ingredient in natural gas, is a good energy source. Most gas furnaces and stoves use methane supplied by utility companies.

In 2003, East Kentucky Power Cooperative began recovering methane from three landfills. The utility now uses the gas at six landfills to generate enough electricity to power about 9,000 Kentucky homes. Today, a small portion of landfill gas is used to provide energy. Most is burned off at the landfill. With today's low natural gas prices, this higher-priced biogas is rarely economical to collect. Methane, however, is a more powerful greenhouse gas than carbon dioxide. It better to burn landfill methane and change it into carbon dioxide than release it into the atmosphere. Methane can also be produced using energy from agricultural and human wastes. Biogas digesters are airtight containers or pits lined with steel or bricks.

Waste put into the containers is fermented without oxygen to produce a methane-rich gas. This gas can be used to produce electricity, or for cooking and lighting. It is a safe and clean-burning gas, producing little carbon monoxide and no smoke. Biogas digesters are inexpensive to build and maintain. They can be built as family-sized or community-sized units. They need moderate temperatures and moisture for the fermentation process to occur. For developing countries, biogas digesters may be one of the best answers to many of their energy needs. They can help reverse the rampant deforestation caused by wood-burning, reduce air pollution, fertilize over-used fields, and produce clean, safe energy for rural communities (Baumann et al., 2012).

2.2.4 Use of Biomass as Energy

The wood is usually burned in order to use the energy for heating purpose. However, burning is not the only way to convert biomass energy into a usable energy source. There are four ways, started with the process of fermentation which is a process of producing alcohol from various plant especially corn. The two most commonly used processes involve using yeast to ferment the starch in the plant to produce ethanol. One of the newest processes involves using enzyme to break down the cellulose in the plant fibers, allowing more ethanol to be made from each plant, because all of the plant tissue is utilized but not just the starch (Baumann et al., 2012). Bacterial decay is another method of producing methane by feeding bacteria on dead plants and animals. Methane is produced whenever organic material decays. Methane is the main ingredient in natural gas, the gas sold by natural gas utilities. Many landfills are recovering and using the methane gas produced by the garbage. Lastly, biomass can be converted into gas or liquid fuels by using chemicals or heat. In India, cow manure is converted to methane gas to produce electricity. Methane gas can also be converted to methanol, a liquid form of methane (Baumann et al., 2012).

In conclusion, biomass is considered as one of the most promising renewable energy sources in the world nowadays. It is utilized as solid, liquid or gas fuel which opts in the field of renewable source of fossil fuel. Especially, lignocellulosic biomass wastes are attracting interest worldwide, because of its non-edible characteristic (Uemura et al., 2011). The non-renewable fossil oils and the application of fossil oils brings environmental problems, especially the carbon dioxide emission in contributes to the issue of global warming. Consequently, these problems motivate scientists and researchers to look for the renewable sources and here comes biomass. The availability of biomass due to its plantation and collected annually ensures a continuous energy supply (Ren et al., 2012). In order to utilize biomass waste efficiently, the following drawbacks about biomass compared to fossil fuels must be solved properly, higher energy consumption for collection, heterogeneous and uneven composition, lower calorific value and difficulty in transportation (Uemura et al., 2011).

2.3 Palm Oil Industry in Malaysia

Palm oil is an agricultural product, which is mainly produced in South-East Asian countries, especially Indonesia and Malaysia. Oil palm waste is generated through the production of palm oil. While in Malaysia, the climate of hot and wet weather throughout the year encourages the growth of the oil palm and consequently the development of oil palm cultivation in Malaysia. This has lead Malaysia as a major global oil palm biomass producer and a main exporter in the world. The total oil palm planted area in Malaysia reached 4.98 Mha as of September 2011 which covers approximately 73% of the agricultural land and makes oil palm a promising raw material for renewable energy generation (Ng et al., 2012).

In the Eight Malaysia Plan in 2001, renewable energy was introduced as the 'fifth fuel' after the four energy sources: oil, gas, hydropower and coal. The fifth fuel has been gaining influence in current energy development as a potential alternative to fossil fuels (National Energy Policies , 2006). According to the study by Sulaiman et al. (2011), energy consumption in Malaysia has been increasing since 1994. The final commercial energy demand by source for the years 2000-2010 is presented in the Table 2.1 (Sulaiman et al., 2011).

Table 2-1: Final commercial energy demand by source for the years 2000-2010 (Sulaiman et al., 2011)

	Average Energy Demand (MW)			**% of Total**		
Source	2000	2005	2010	2000	2005	2010
Petroleum Products	26002	32442	43534	65.9	62.7	61.9
Natural Gas	5131	7820	11098	13	15.1	15.8
Electricity	6989	9830	13318	17.7	19	18.9
Coal and Coke	1316	1649	2378	3.4	3.2	3.4
Total	39437	51741	70329	100	100	100

As can be seen, Malaysia is highly dependent on fossil oil as an energy source. Malaysia is working towards fuel diversification to reduce its dependency on fossil fuels in order to improve the energy security. Palm biomass appears to be one of the potential energy sources due to its abundance. In addition, the realisation of palm biomass for producing value-added products and biochemical increases the business opportunities for the palm biomass industry. The industry is forecasted to evolve as a major sector in Malaysia's future development. Green development indicators are of the utmost importance in ensuring economic and sustainable development (Sulaiman et al., 2011).

Despite the large amount of palm oil production, the oil contributes to less than 25% by weight of the palm fruit bunch (FAO, 2011). For every kg of palm oil produced, approximately four kg of dry biomass is produced, excluding palm oil mill effluent (POME). In 2010, 88.74 Mt of Fresh Fruit Bunch (FFB) of oil palm was processed (GGS, 2011). The amount of biomass available from the stated is listed in the Table 2.3(b). The production of palm biomass was approximately 87 Mt in 2010, although this value excludes oil palm fronds and trunks, which would further increase the amount of biomass produced by the palm oil industry (GGS, 2011). The potential energy that can be generated is calculated in Table 2.3(b) and totals up to 37 Mt/y of oil equivalent based on the amount of biomass available as of 2010. This amount of energy may be wasted due to the inefficient utilisation of the available palm biomass. To date, 60 MW out of 68 MW of biomass power is generated from palm biomass. The government of Malaysia has set a target to increase its biomass power generation capacity to 800 MW by 2020, and 500 MW is to be generated from palm biomass (Kementerian Tenaga, 2011). The cumulative renewable energy target on biomass projected by the Ministry of Energy, Green Technology and Water (Kementerian Tenaga, 2011) is illustrated in Figure 2.2.

Table 2-2: Potential Energy that can be generated (Sulaiman et al., 2011)

Biomass Available	Quantity (Mt/y)	Net Calorific Value (MJ/t)
Empty Fruit Bunch (EFB)	21.27	18795
Mesocarp Fiber	10.8	19055
Palm Kernel Shell	4.98	20093
Palm Oil Mill Effluent (POME)	49.85	16992
Total	86.9	

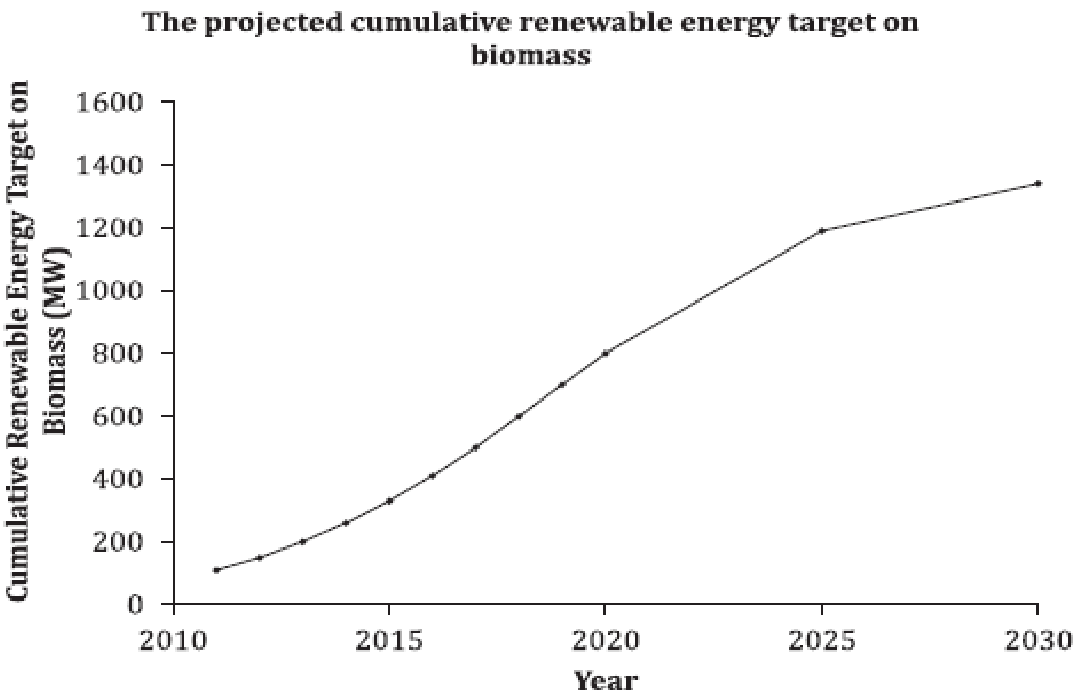

Figure 2-2: Cumulative Renewable Energy target on Biomass Projected (Sulaiman et al., 2011)

2.4 Palm Oil Solid Wastes

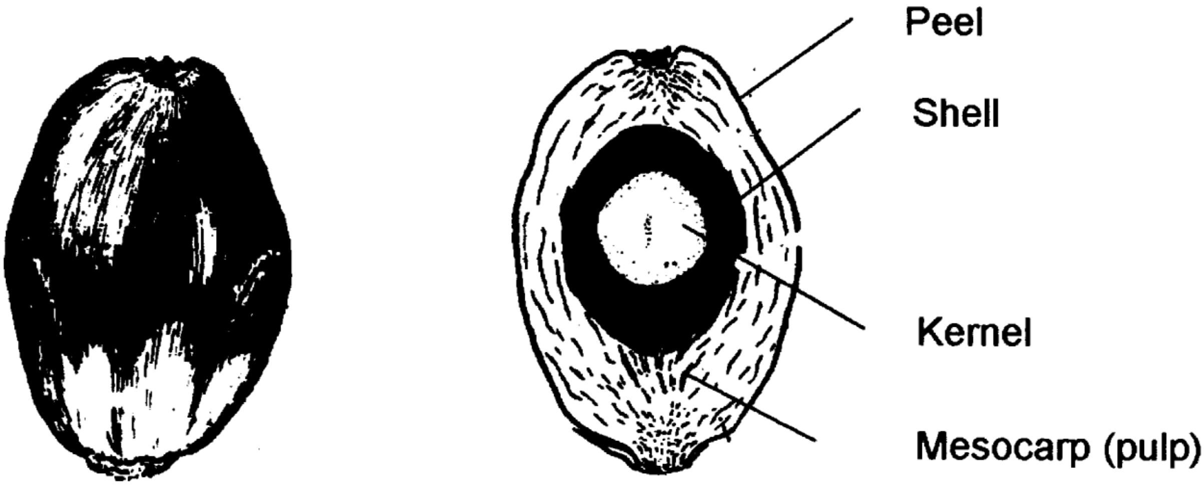

Figure 2-3: Fresh oil palm fruit and its longitudinal section (Guo & Lua, 2001)

Figure 2.3 showed a fresh oil palm fruit and its longitudinal section. During palm oil plantation and processing, a large amount of solid wastes such as palm trunks, palm fronds, empty fruit bunches (EFB) and fruit wastes which including the extracted mesocarp fibers and palm shells, are generated (Guo & Lua, 2001). In Malaysia, which is one of the largest palm oil producer in the world, about 2 million tons (dry weight) of palm shells and 1 million tons of extracted fibers are estimated to be produced annually. Normally, these waste are used as boiler fuel or chemical feedstock for solid (char), liquid (aqueous and tar fractions) and gaseous products (Guo & Lua, 2001). Figure 2.4 shows the process flow diagram of a palm oil mill where to obtain the waste needed in the study which is EFB, mesocarp fiber and kernel shell.

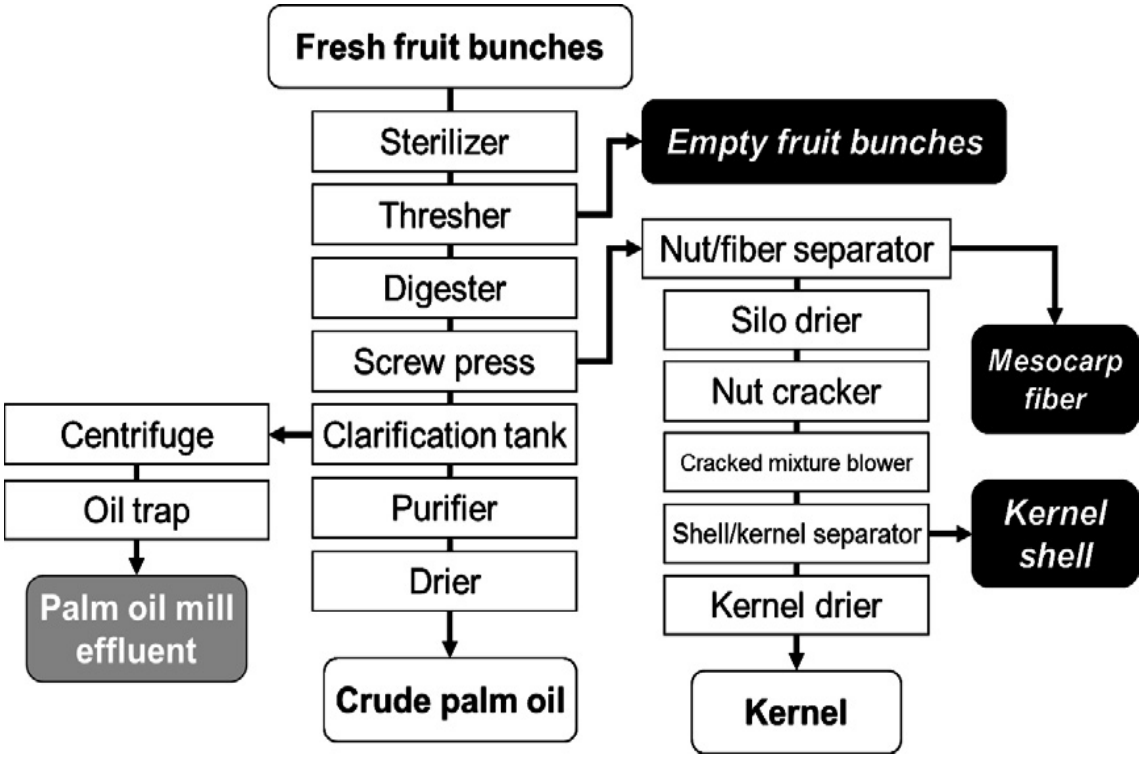

Figure 2-4: Process flow diagram of palm oil mill (Uemura et al., 2011)

2.4.1 Empty Fruit Bunches (EFB)

According to Singh et al., 2010, **a**n average oil palm mill can handle about 100 metric tonnes (mt) of fresh fruit bunches daily. Solid residues and liquid wastes are generated at the mills where oil extraction takes place. The solid residues, mainly EFB, are more than 20% of the fresh fruit weight. The EFBs are either incinerated or applied to fields. These practices create environmental pollution problems such as incineration and boilers emits gases with particulates such as tar and soot droplets of 20-100 microns and a dust load of about 3000-4000 mg/nm and indiscriminate dumping of EFB causes additional methane emission into the atmosphere (Amal et al., 2008). A new usage for these wastes ought to be looked into in order to minimize the pollution.

EFB is a suitable renewable raw material for bioconversion into value added products because it is easily accessible, abundant locally and rich in lignocellulose as shown in Table 2.3 below.

Table 2-3: Fibrous composition of major constituents in EFB (%) (Mohammaad et al., 2011)

Components	Sreekala et al. (1997)	Khalil et al. (2007)
Lignin	25-35	21.2
Cellulose	45-50	49.6
Hemicellulose	25-35	18
Ash	-	2

EFB was often used as fuel to generate steam at the palm oil mills. However, the air pollution from EFB burning caused serious environmental concerns and the authorities formulated tight regulatory controls to curb air-pollution from such activities. EFB is now mainly used as mulch in the palm oil plantations to control weeds, prevent erosion and maintain soil moisture. However, due to escalating labor, transportation and distribution costs of EFB in the field, its utilization as mulch is becoming more expensive. There is a growing interest in the low and cost attractive solid state bioconversion of EFB into value added products, such as compost, citric acid or enzymes (Alam et al., 2009). Table 2.4 showed the approximate compositions of major constituents in EFB.

Table 2-4: Approximate compositions of major constituents in EFB (%) (Mohammad et al., 2011)

Nutrients	Amal et al. (2008)	Suhaimi and Ong (2001)	Hajar (2006)	Rozainee et al. (2001)
C	48.8	43.7	42-43	50.09
Nutrients	0.2	0.52	0.65-0.94	2.05
C.N	-	-	45-64	-
P	-	0.05	-	-
H	6.3	-	-	7.16
O	36.7	-	-	40.16
K	-	1.34	-	-
S	0.2	0.07	-	0.06
B	-	4	-	-
CA	-	0.19	-	-
CU	-	13	-	-
Mn	-	-	-	-
Mg	-	20	-	-
Zn	-	21	-	-